



Development of Early-Indicators for Failure-Prognosis of Electronics

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Objectives

Develop technologies to determine system/component degradation and damage significantly prior to failure.

Enable nearly continuous on-board situational awareness of the vehicle electronic-system health state.

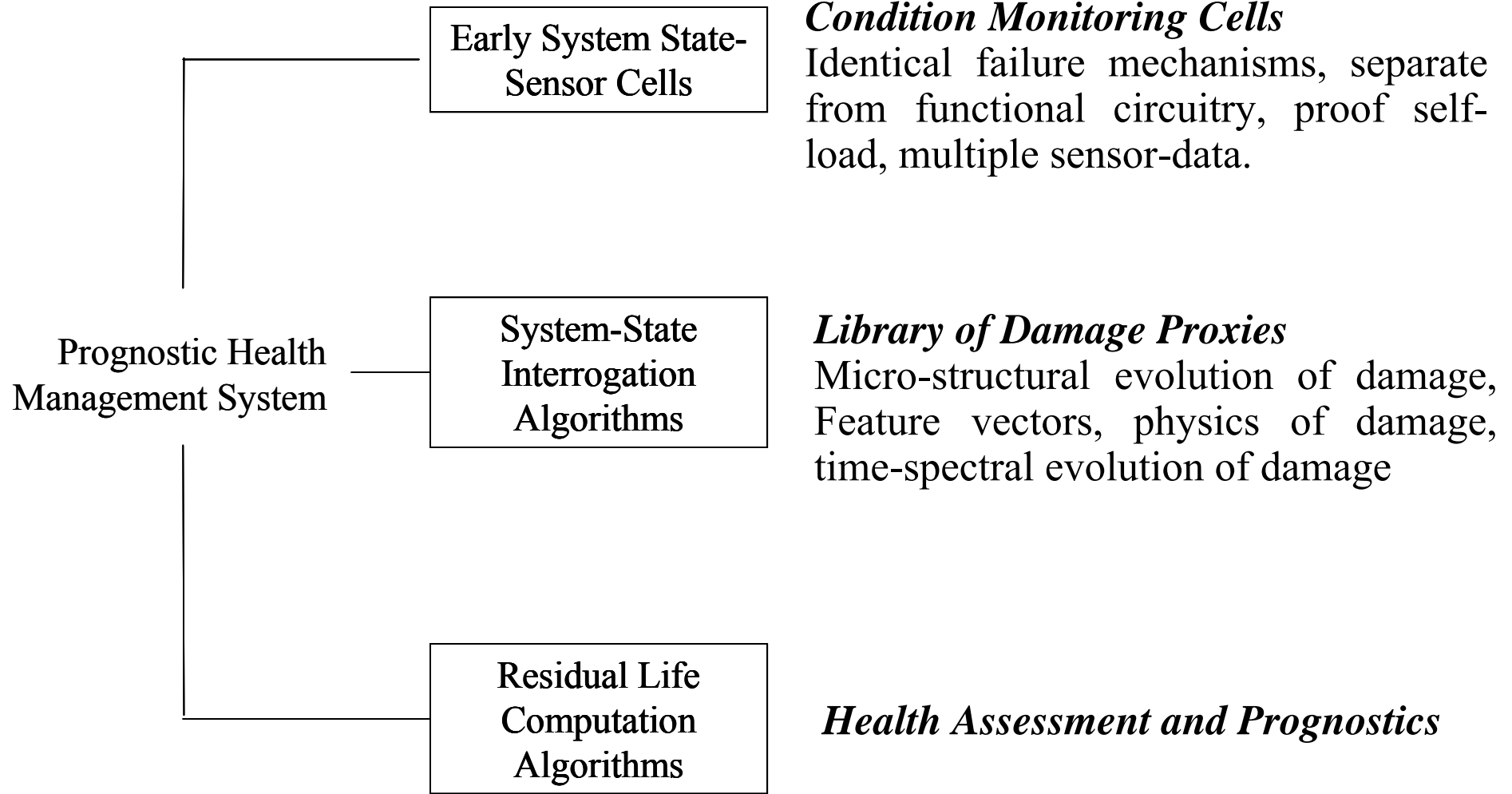
Understand fault modes associated with high-power electronics, and lead-free solder joints, new packaging architectures.

Develop automatic methods for detection, diagnosis, and prognosis of the vehicle at a system and subsystem level.

Develop capabilities for analyzing effects of environmental hazards on vehicle electronics, damage and degradation mechanisms to assess the vehicle's health state.

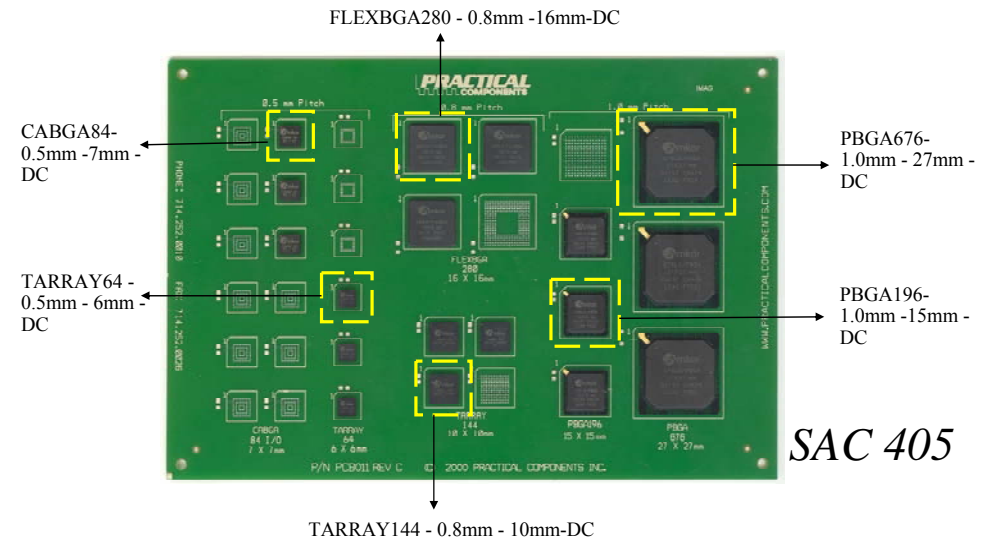
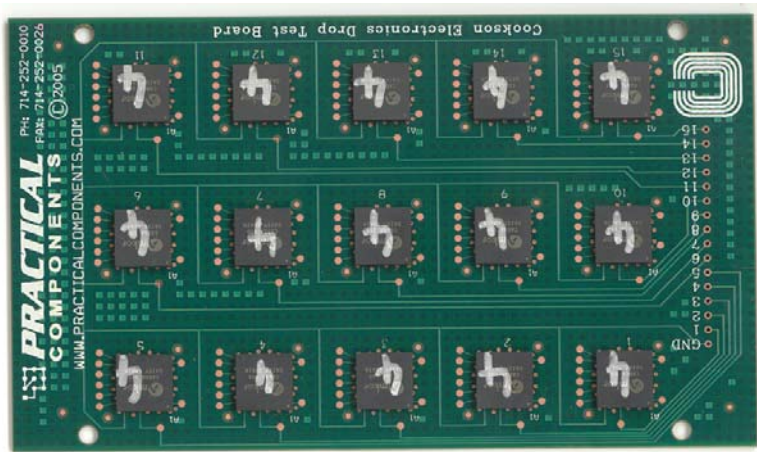


Approach to Prognostics Framework





Test Vehicles



CABGA100
0.8mm Pitch
10mm

SAC Alloys

1. SAC105
2. SAC305
3. SAC0307
4. SACX
5. SACX-plus
6. Sn3.5Ag

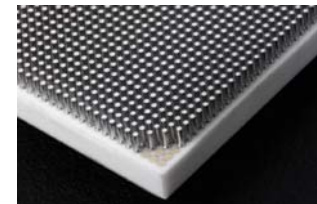
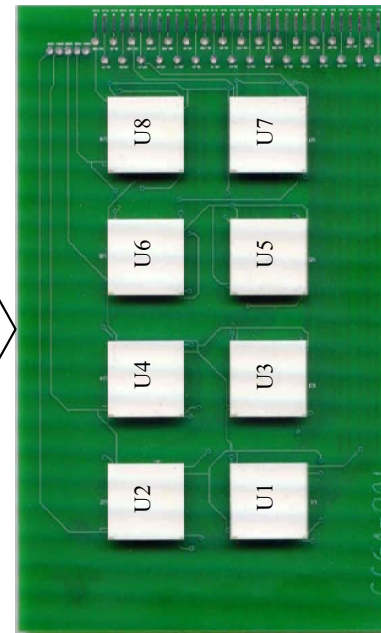
Cu-Reinforced
Solder Columns
Sn15/Pb85

Micropearl
SOL650 SnAg
Finish

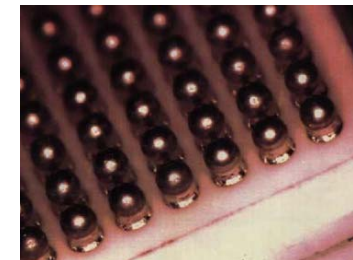
Sn10/Pb90

96.5Sn3Ag0.5Cu

63Sn37Pb



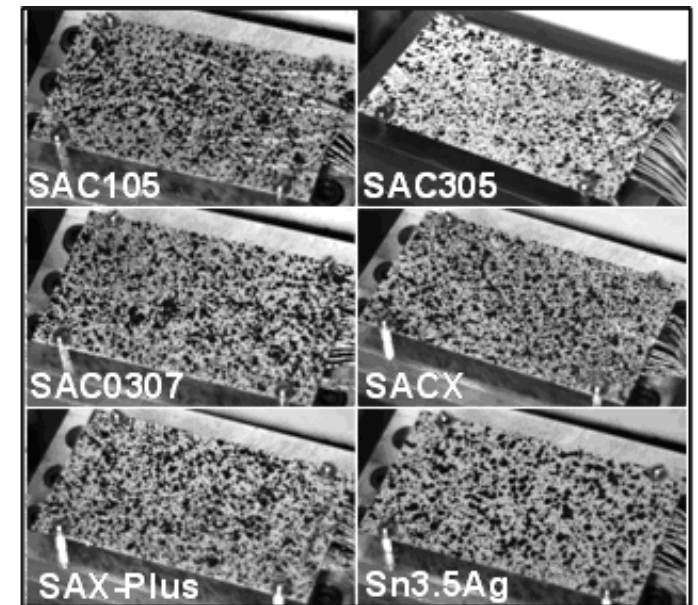
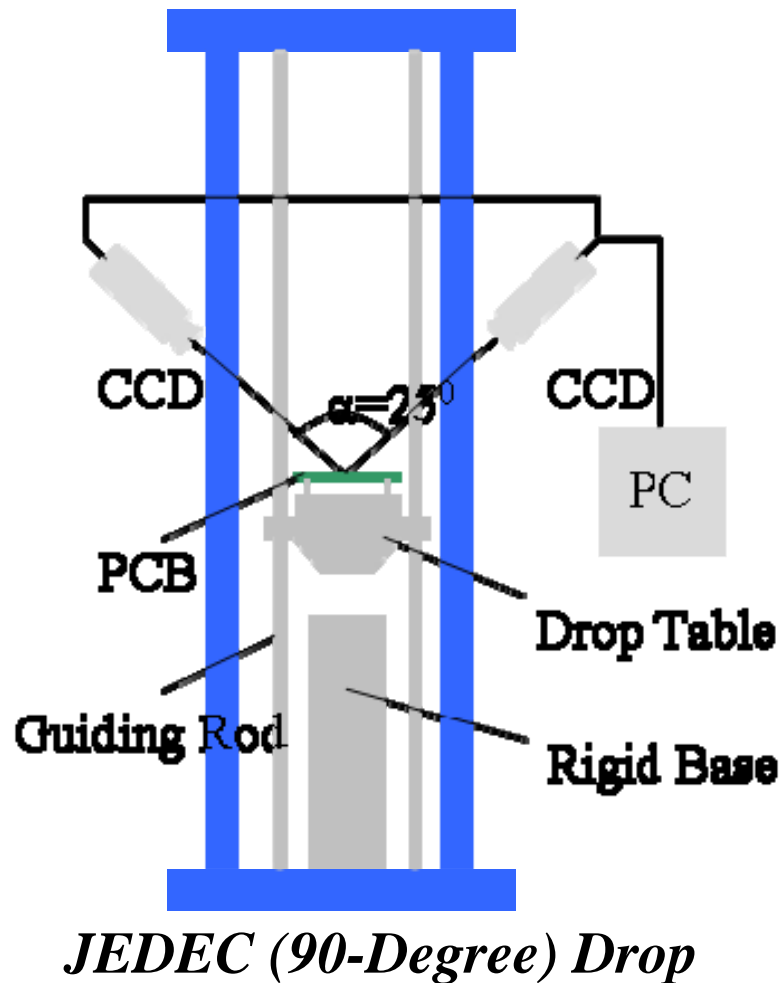
CCGA



CBGA



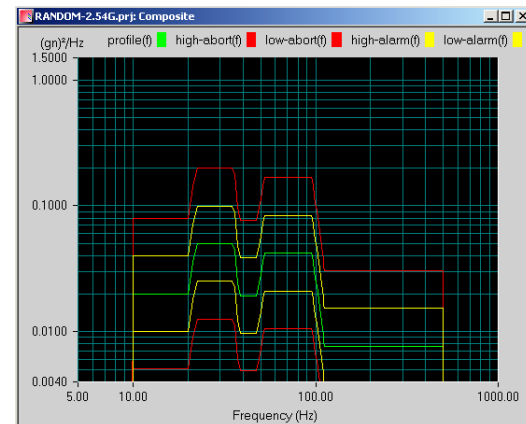
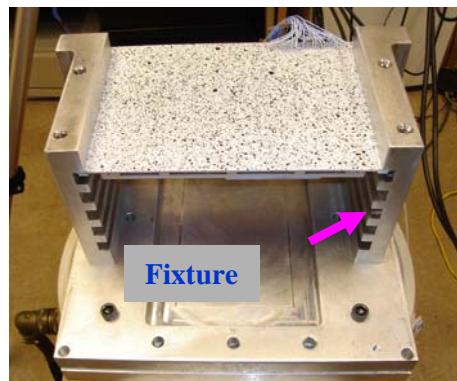
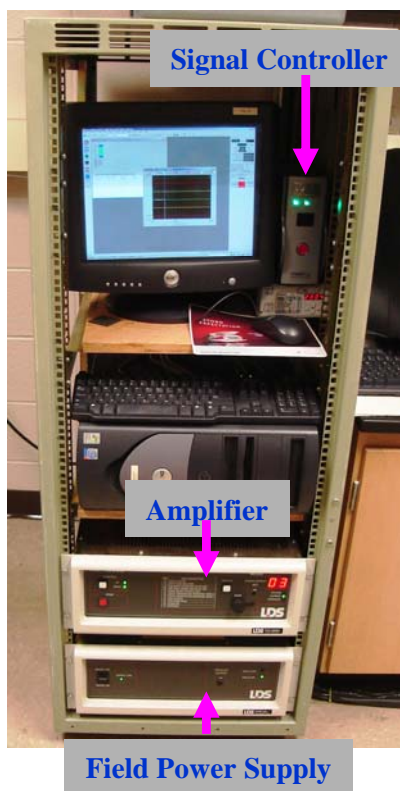
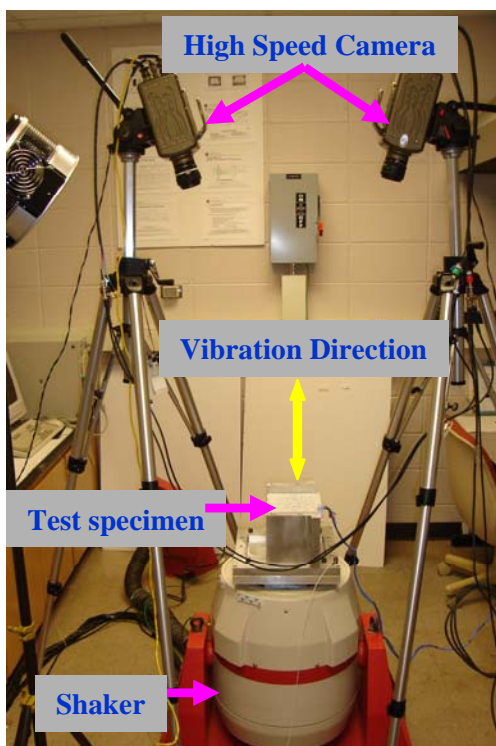
DIC Experimental Set-up



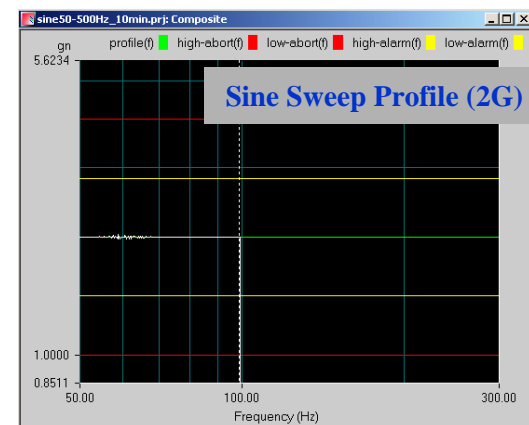


Vibration Testing

- Experimental Setup



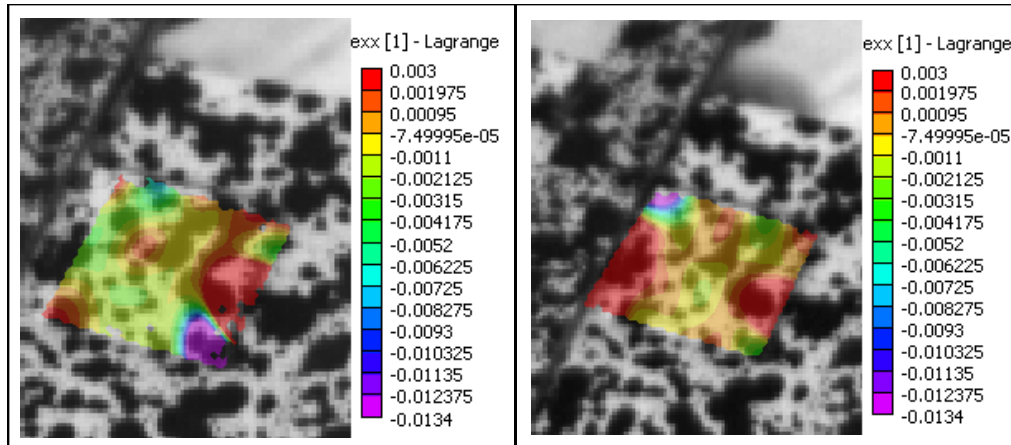
Random Profile from
12-500 Hz at 2.54 Grms



Sine Sweep from
50-500 Hz at 2G



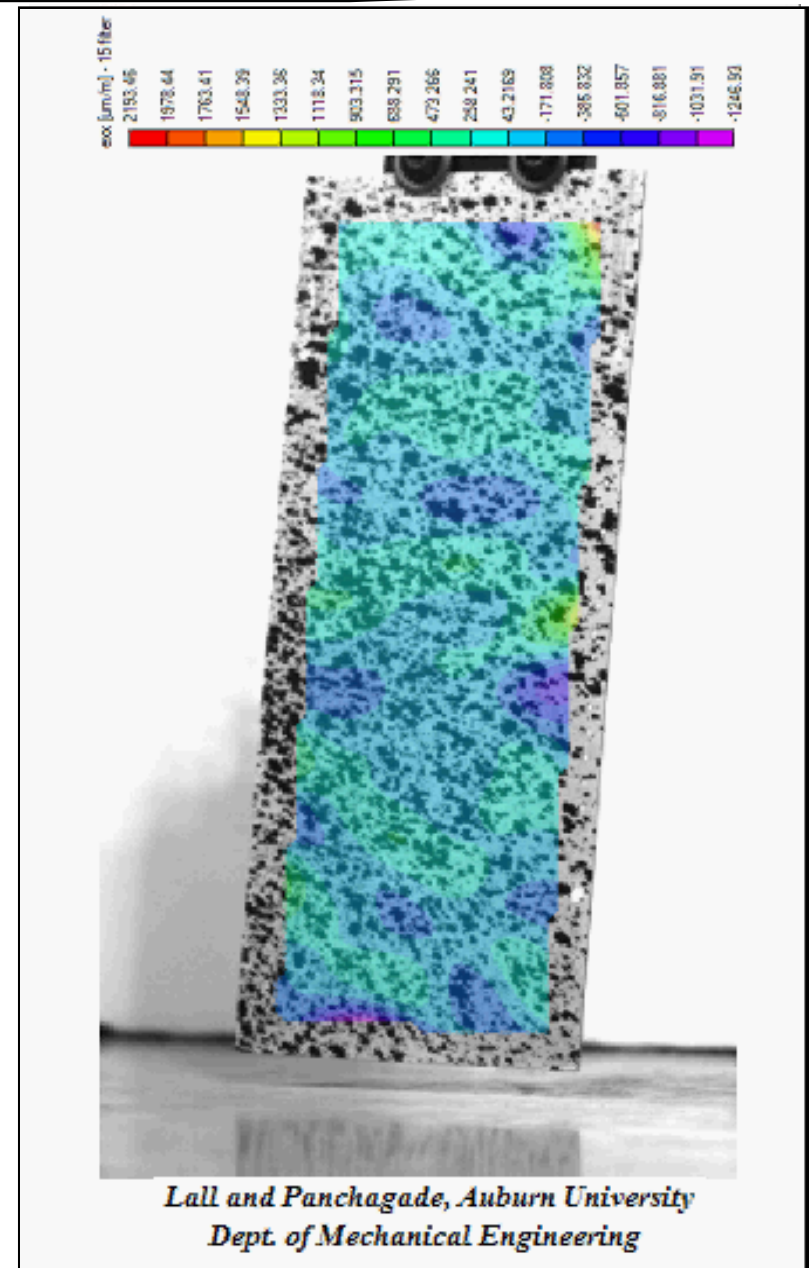
Digital Image Correlation



SACX – plus; Drop
78; $t = 1.98\text{ms}$,

SACX – plus; Drop 430;
 $t = 1.98\text{ms}$,

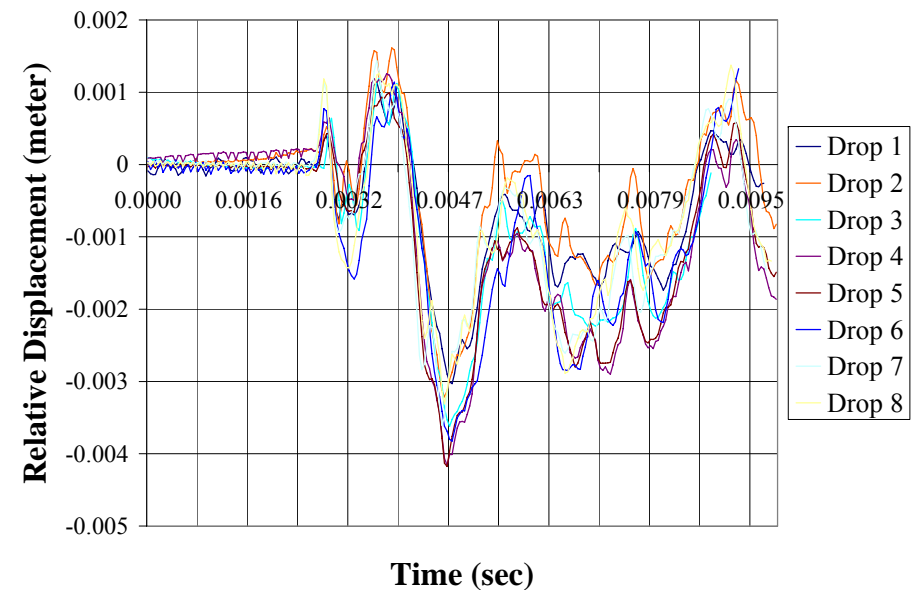
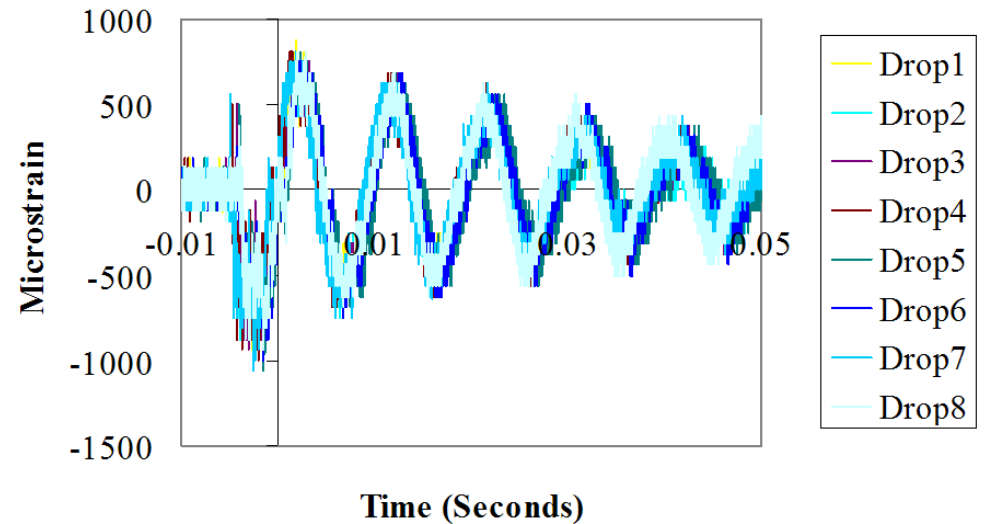
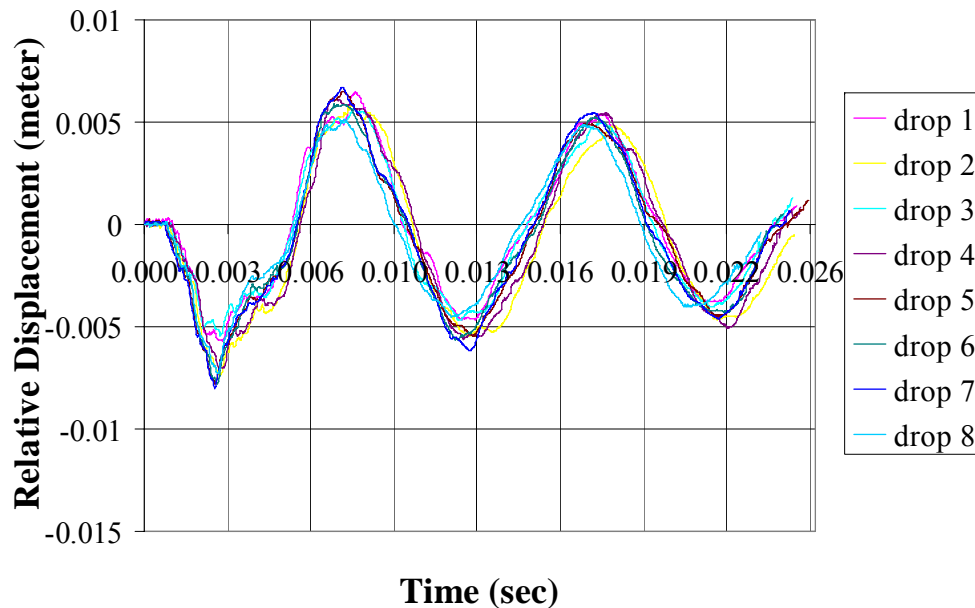
*2D strain contours at package location 13
before and after failure for the SACX-
Plus alloy system*





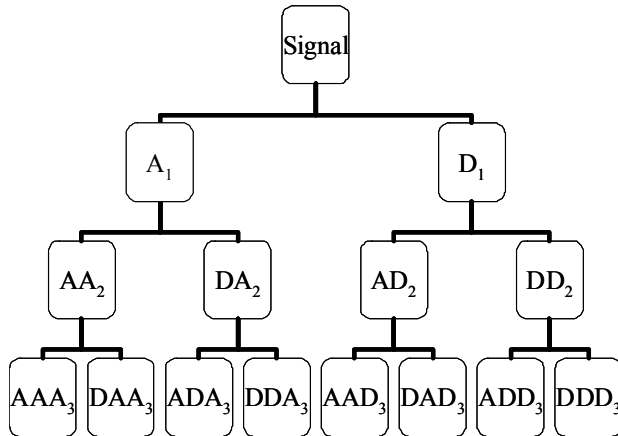
Repeatability of Drop Orientation

Test Board B		Test Board A	
Standard deviation (degrees)	Mean Value (degrees)	Mean Value (degrees)	Standard deviation (degrees)
0.87	0.2	0.34	0.90

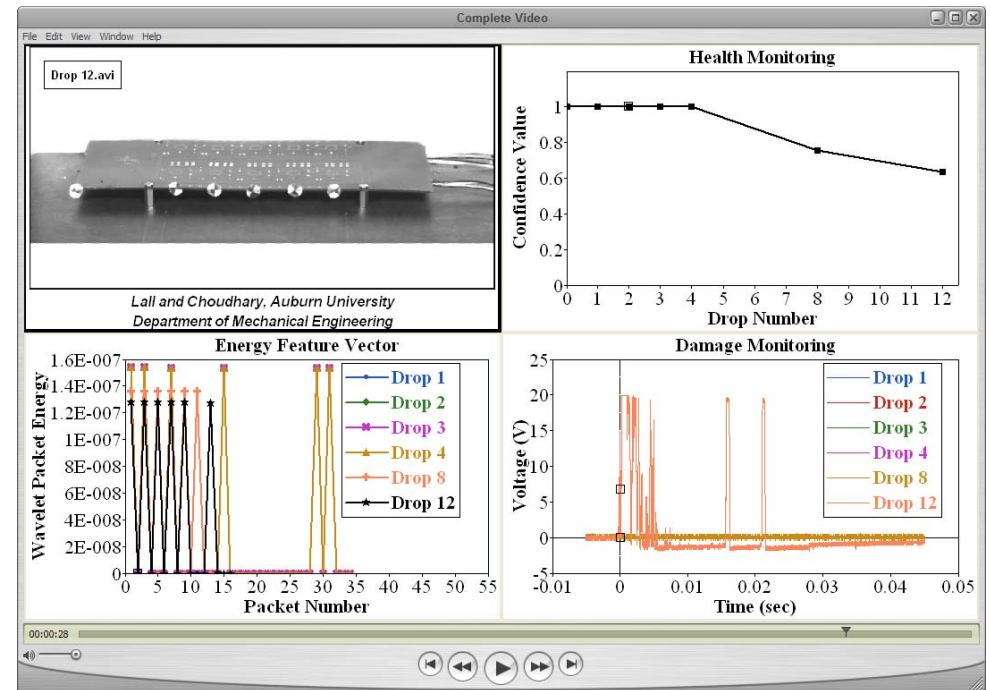
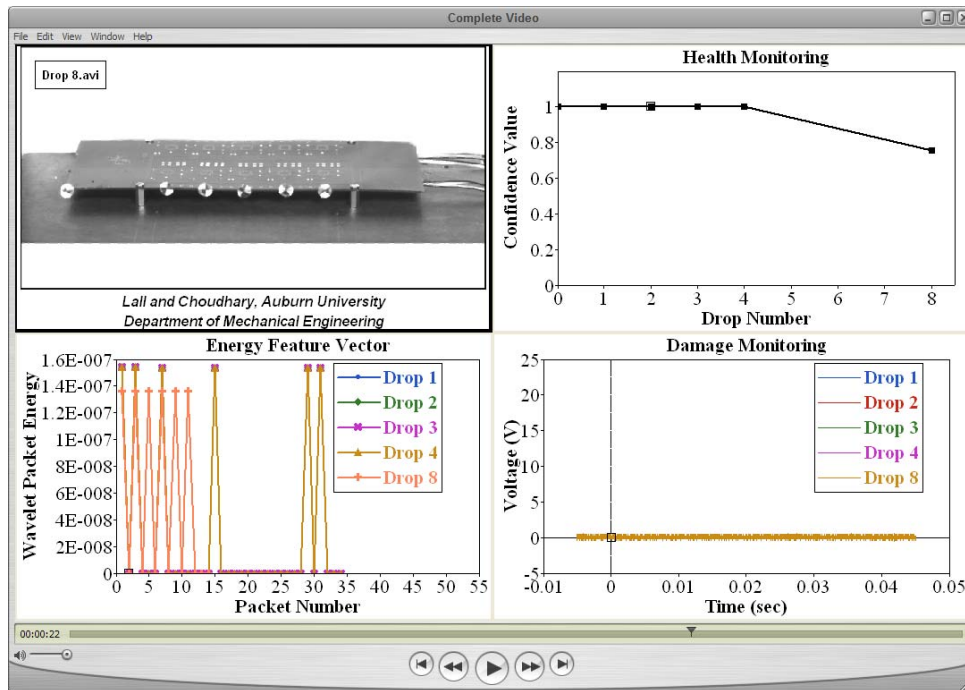
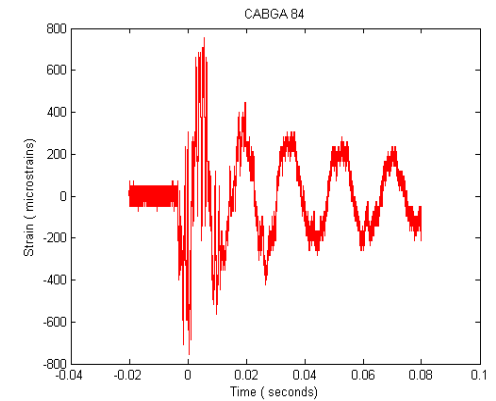




Wavelet Packet Decomposition



$$W_f(u, s) = \langle f, \psi_{u,s} \rangle$$
$$= \frac{1}{\sqrt{s}} \int_{-\infty}^{+\infty} f(t) \psi^* \left(\frac{t-u}{s} \right) dt$$





Statistical Pattern Recognition Techniques

Group of Values: $(\mu_1, \mu_2, \mu_3, \dots, \mu_n)$

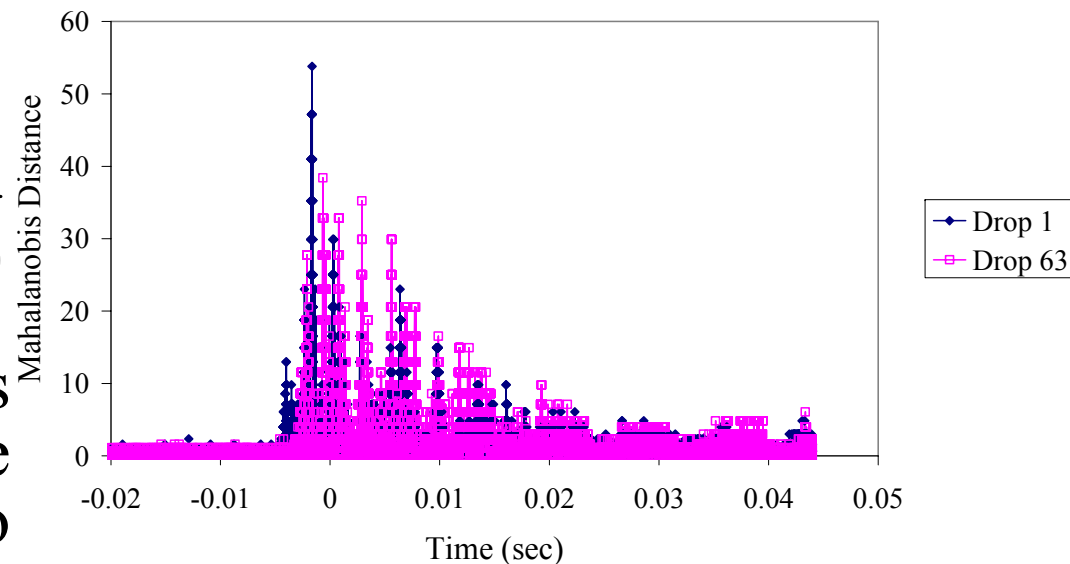
Covariance Matrix: $\sum_{ij} = \text{cov}(x_i, x_j) = \frac{1}{n-1} \langle (x_i - \mu_i)(x_j - \mu_j) \rangle$

Mahalanobis Distance Computation

$$D_M(x) = \sqrt{(x - \mu)^T \Sigma^{-1} (x - \mu)}$$

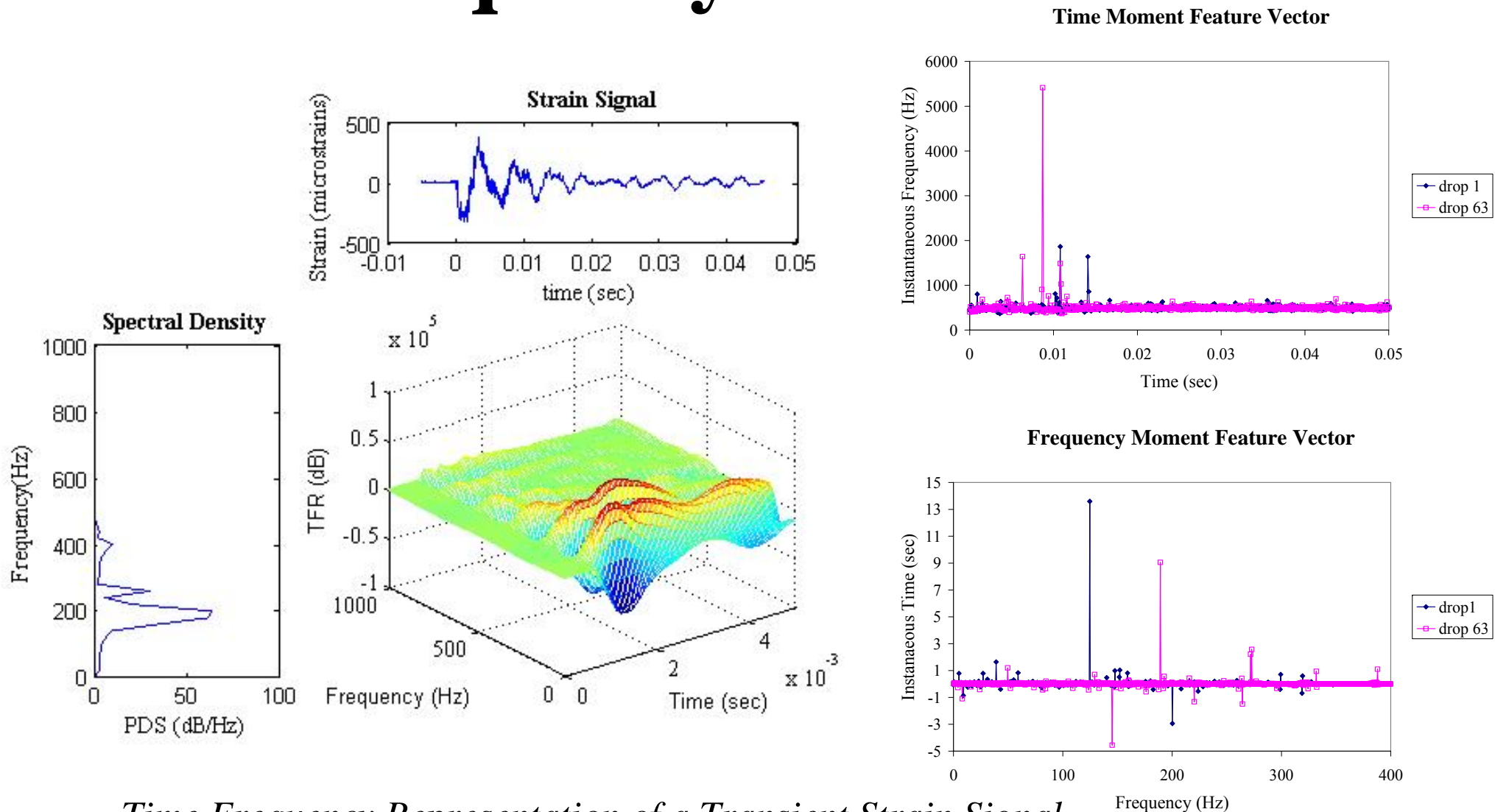
$$d(\vec{x}, \vec{y}) = \sqrt{(\vec{x} - \vec{y})^T \Sigma^{-1} (\vec{x} - \vec{y})}$$

Mahalanobis distance accounts for the variance and covariance of the variables as opposed to only the average value.



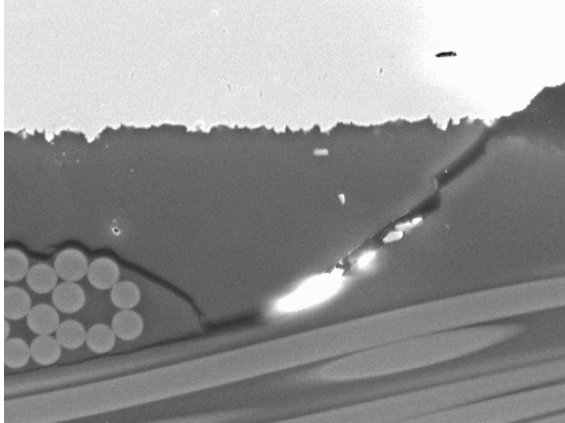


Time Frequency Distribution

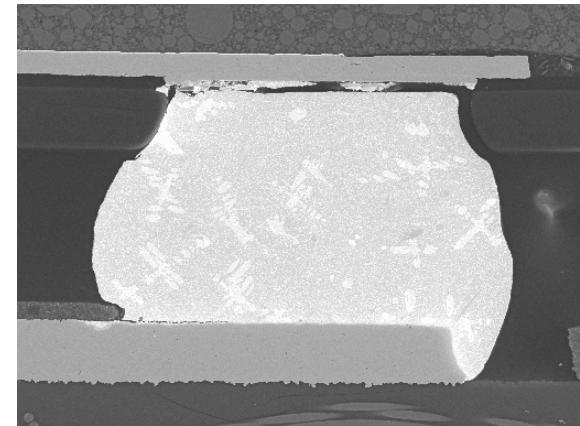




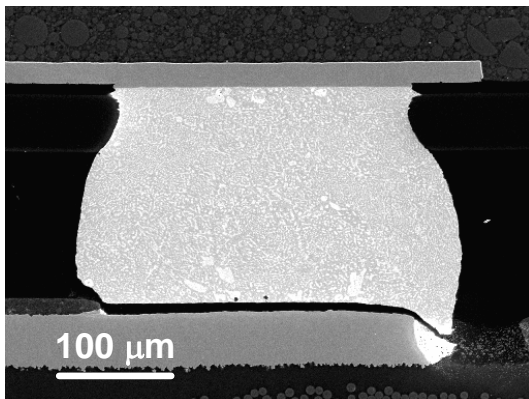
Failure Mechanisms



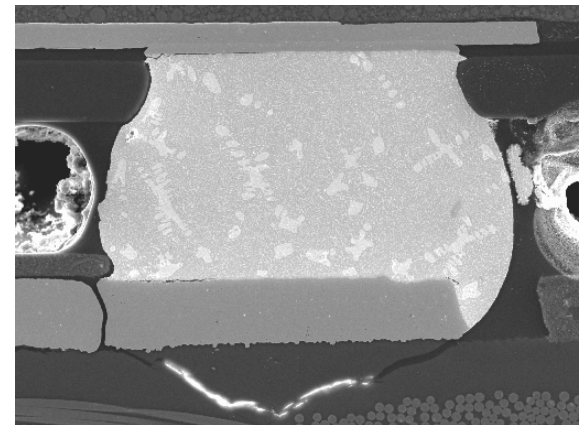
Pad I/O PCB side Resin Crack.



Failed Solder Joint at Package Interface



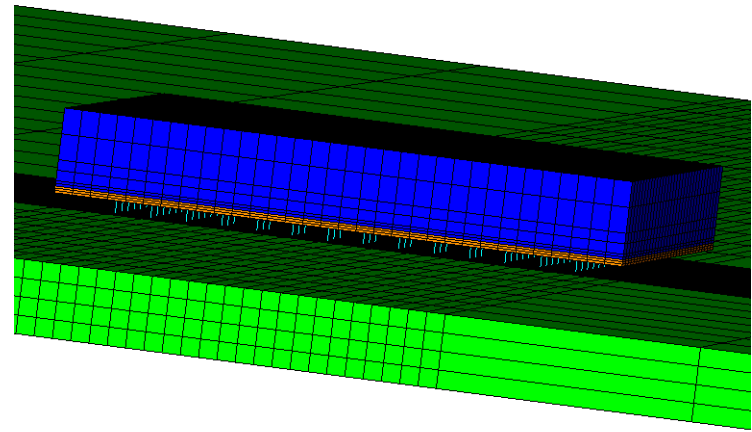
Failed Solder Joint at board-interface



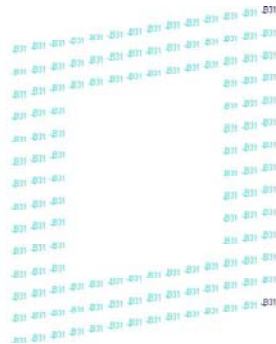
Cracking of Copper and Laminate



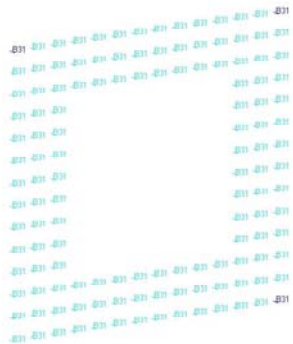
Partial Solder-Ball Cracking



One Solder Beam Cracked
(a)



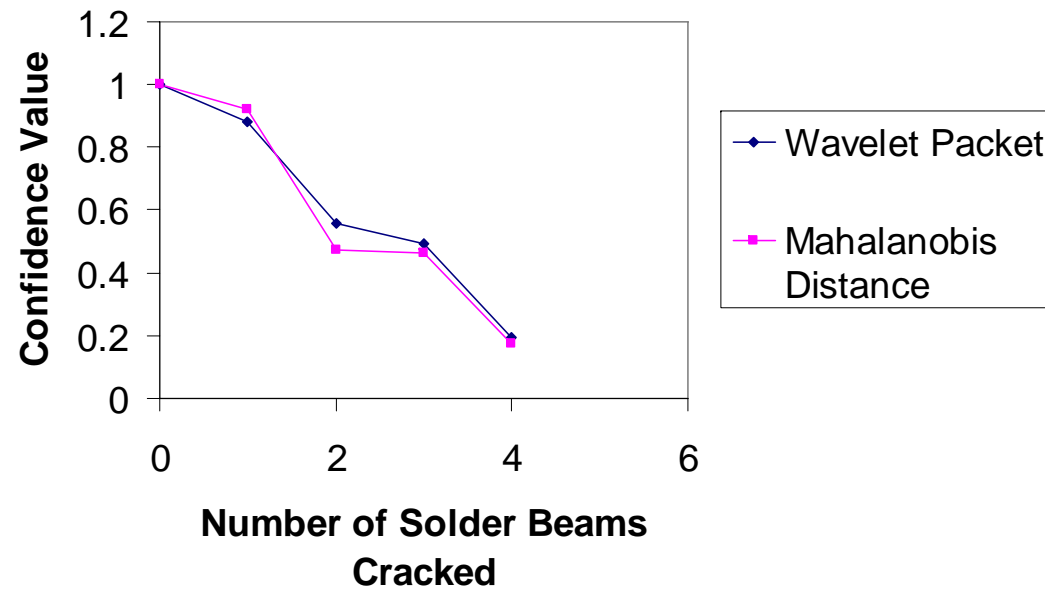
Two Solder Beams Cracked
(b)



Three Solder Beams Cracked
(c)



Four Solder Beams Cracked
(d)



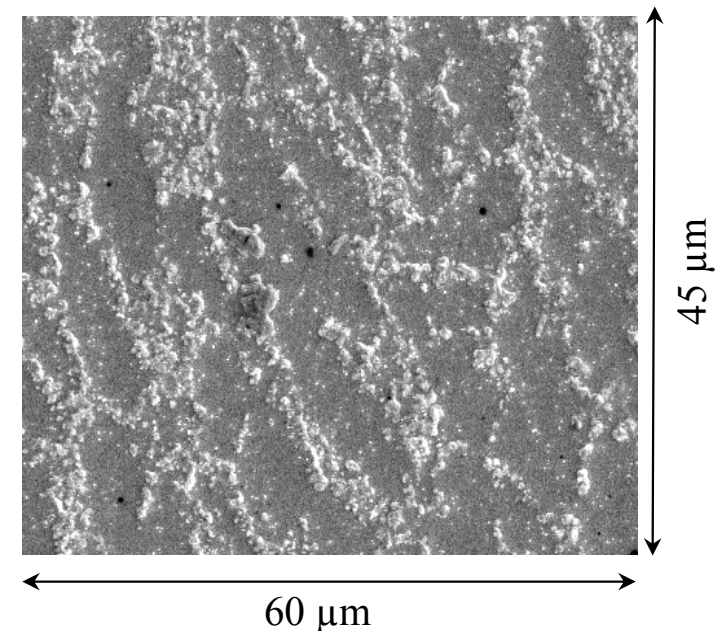
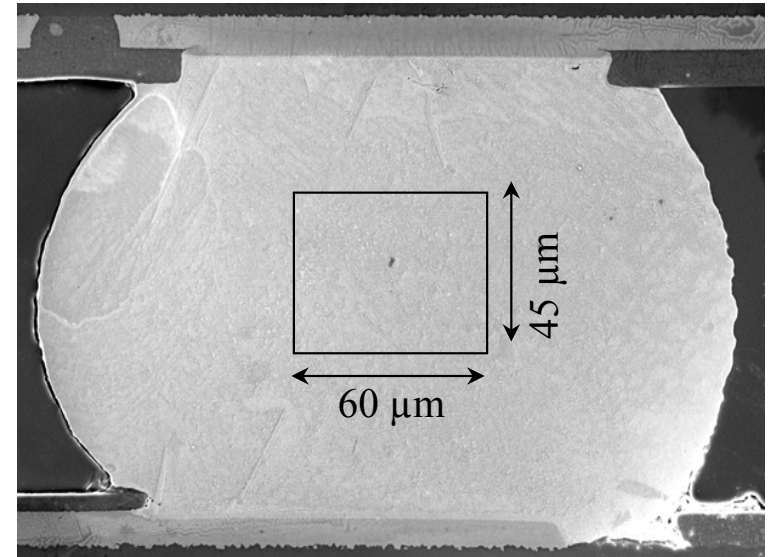


Solder Phase Growth

Cross-sectioned samples at various levels of thermal cycling and thermal aging

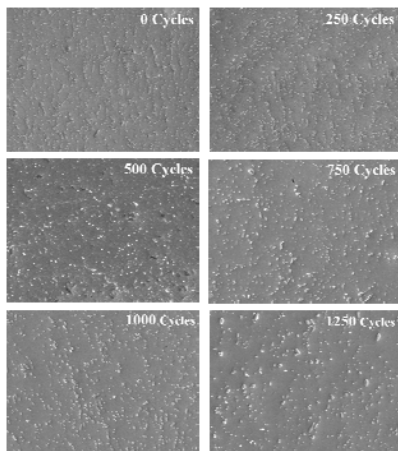
Cross section studies under SEM JEOL JSM-7000F.

Measured the Ag_3Sn particle size (g) from a $60\text{ }\mu\text{m} \times 45\text{ }\mu\text{m}$ rectangular region selected from a backscattered SEM image of a highest strain corner solder ball

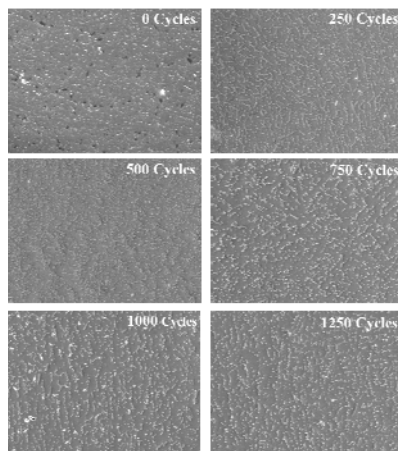




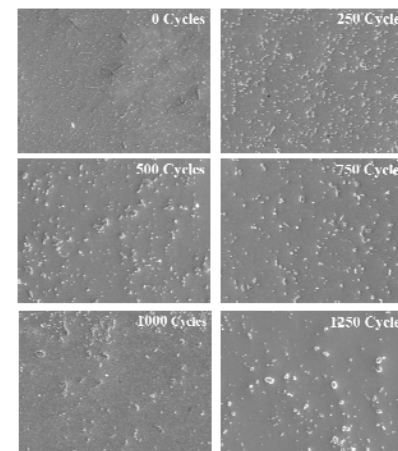
Indicators of Damage > *Cyclic Thermo-Mechanical Loads*



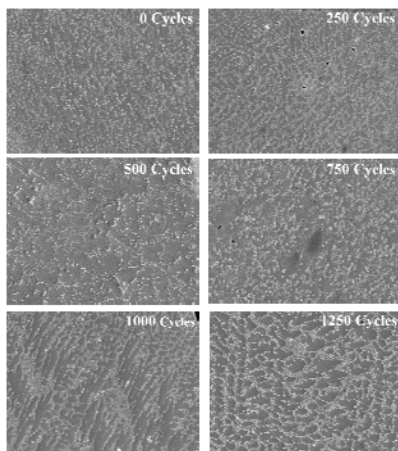
SAC105



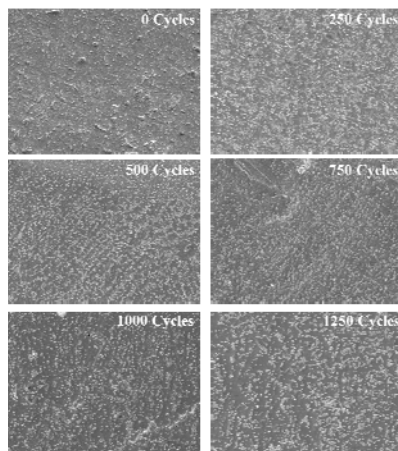
SAC305



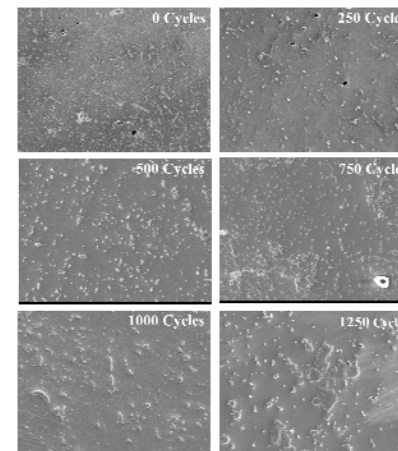
SAC0307



96.5Sn3.5Ag



SACX

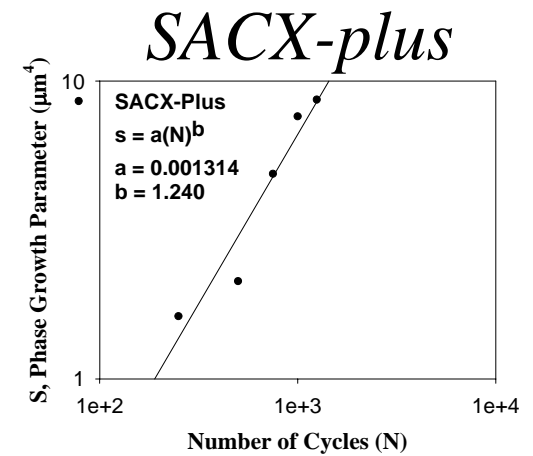
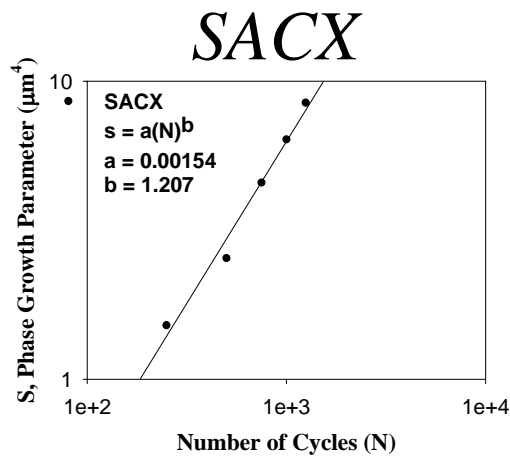
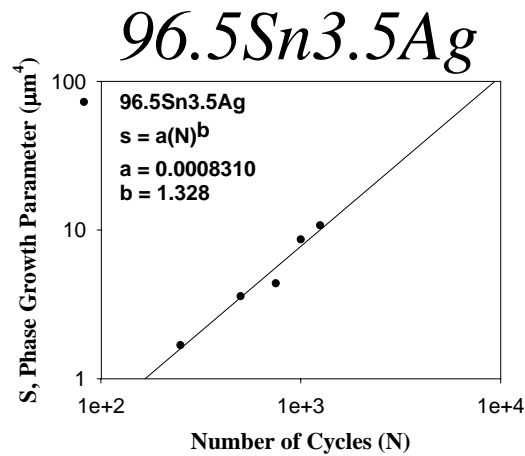
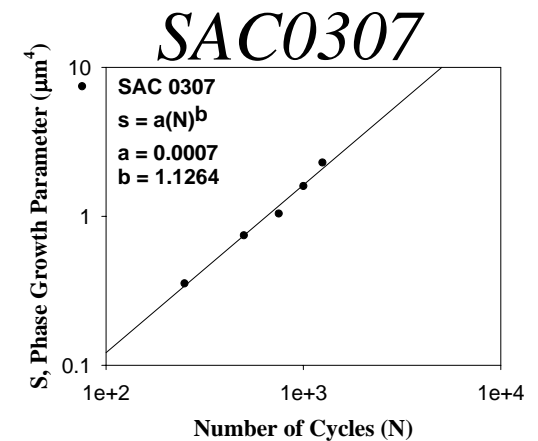
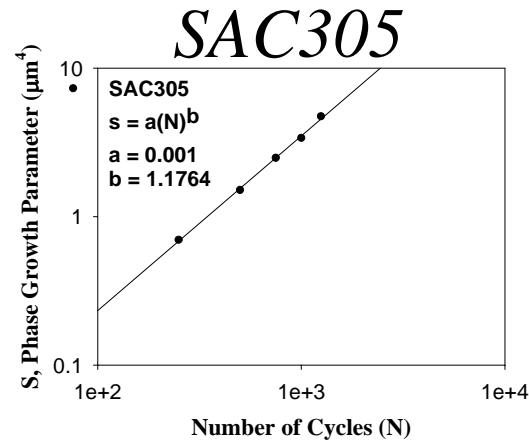
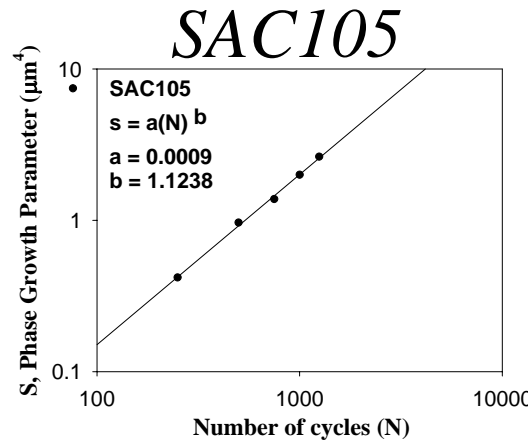


SACX-plus



Progression of Damage Pre-Cursors

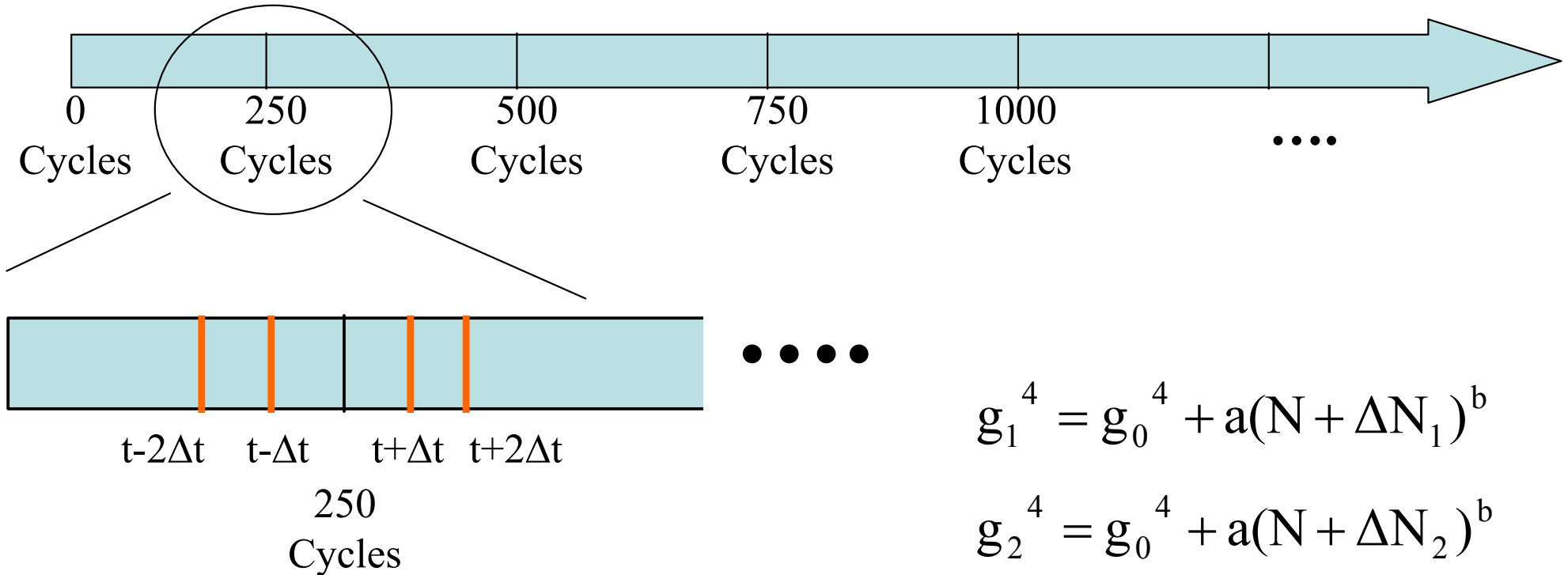
> Phase Growth Measurements - Thermal Cycling





Case 1: Thermo-Mechanical Loads

> Interrogate System State in Prognostication Time-Neighborhood



Alloy System	Constant 'a'	Constant 'b'	Initial Grain size 'g ₀ '
SAC105	0.0004 – 0.0013	1.10 – 1.20	0.92 – 1.02
SAC0307	0.00005 - 0.003	1.00 - 1.25	0.95 - 1.15

Trust Region

$$g_1^4 = g_0^4 + a(N + \Delta N_1)^b$$

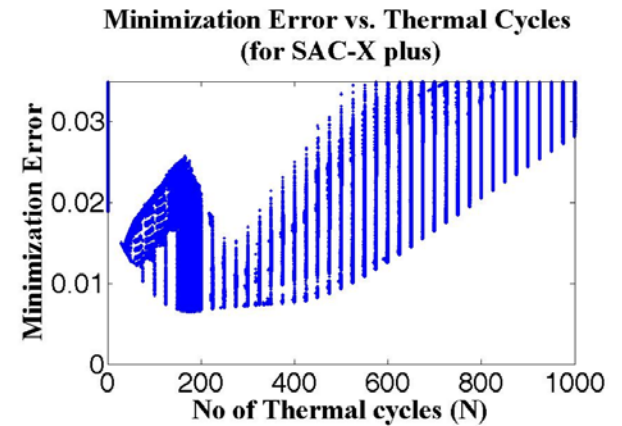
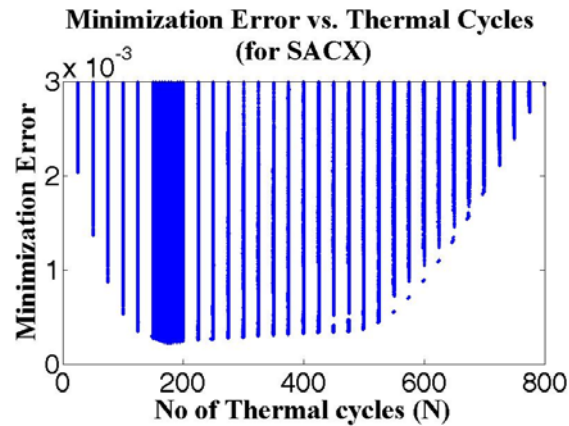
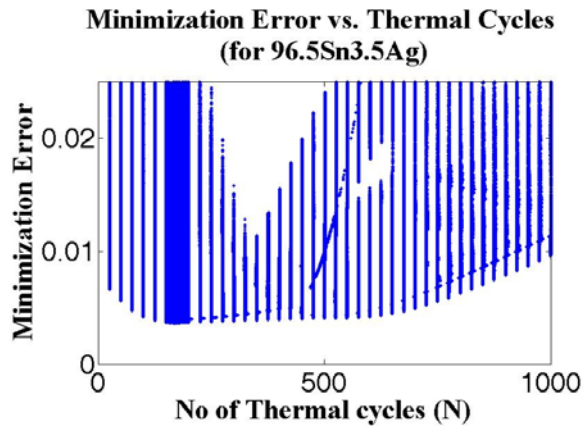
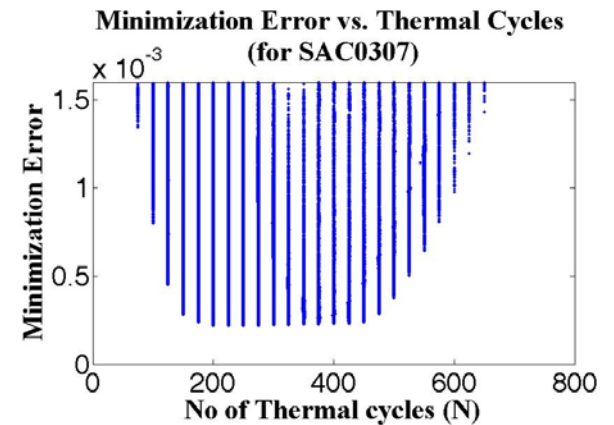
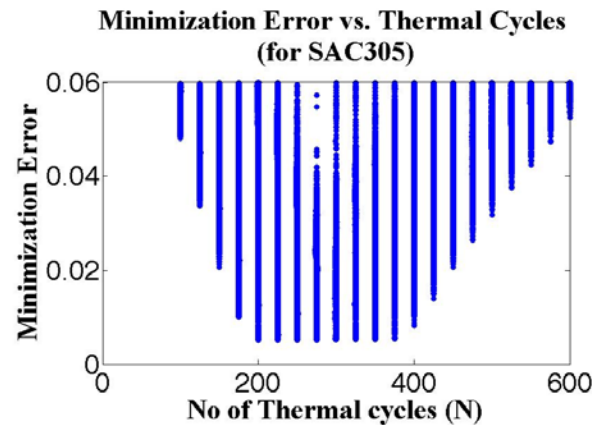
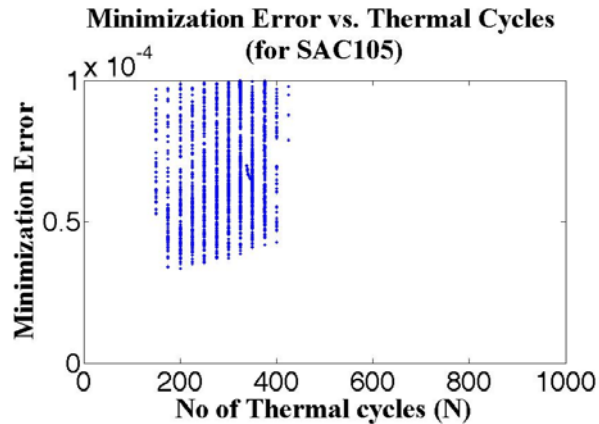
$$g_2^4 = g_0^4 + a(N + \Delta N_2)^b$$

$$g_3^4 = g_0^4 + a(N + \Delta N_3)^b$$

$$g_4^4 = g_0^4 + a(N + \Delta N_4)^b$$



Interrogation of System State





Interrogation of System State

ΔT : 250 Cycles

Alloy System	Cycles 'N'		Grain Size (μm)		Constant 'a'		Constant 'b'	
	Expt	LM	Expt	LM	Expt.	LM	Expt.	LM
SAC 105	250	200	0.978	1.012	8e-4	4.9e-4	1.135	1.199
SAC 305	250	200	1.039	1.069	1e-3	1.3e-4	1.176	1.138
SAC 405	250	225	0.839	0.822	3e-4	4.4e-4	1.216	1.151
SAC 0307	250	225	0.909	0.949	7e-4	5e-4	1.126	1.200
SACX	250	177	1.555	1.60	1.5e-3	0.9e-3	1.207	1.280
SACX-plus	250	175	1.113	1.20	1.3e-3	0.7e-3	1.240	1.330
Sn3.5Ag	250	175	1.429	1.50	8.1e-4	6e-4	1.328	1.369

T-Aging: 666 Hours

Alloy System	Aging Time (hrs)		IMC 'y ₀ ' (μm)	
	Expt	LM	Expt	LM
SAC 105	667	621	2.889	2.829
SAC 305	667	625	2.684	3.039
SAC 405	22	28	3.400	3.310
SAC0307	667	690	3.456	3.687
SACX	667	830	3.935	3.661
SACX-plus	667	830	3.912	3.912
Sn3.5Ag	667	915	6.123	6.100



Model Validation

Interrogate system state in the time-neighborhood of 250 cycles.

Assessment of prior damage.

Determination of residual life.

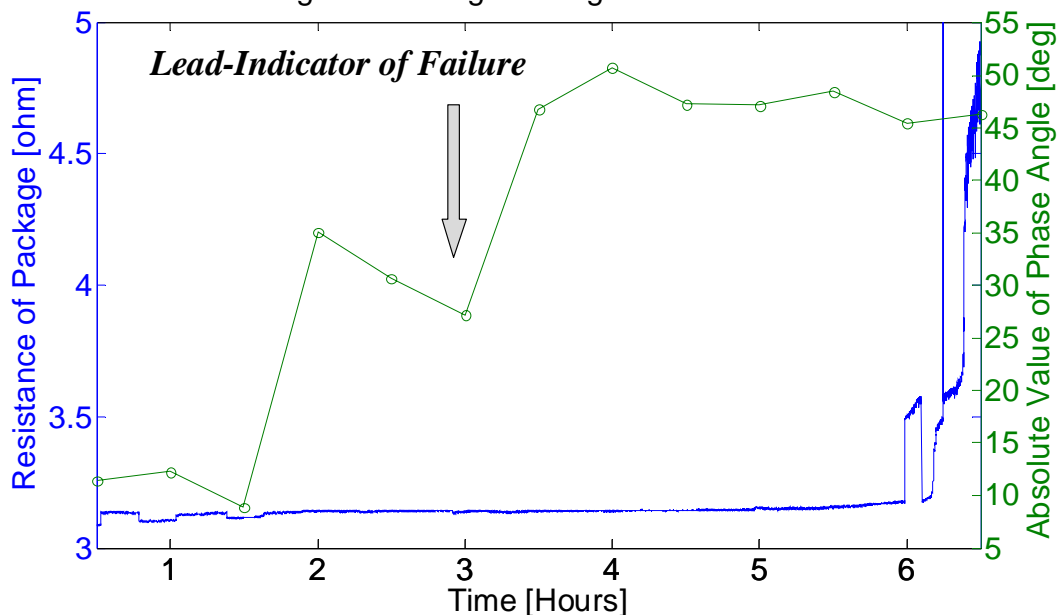
	Experiment				Model Predictions			
	dS/dN	N1%	N	RL	dS/dN	N1%	N	RL
P676	1.1167	3219	250	2969	0.8916	2570	229	2341
F280	1.1434	1989	250	1739	0.8756	1523	332	1191
T144	1.1860	2004	250	1754	1.2272	2073	230	1843
T64	1.3310	1933	250	1683	1.1447	1662	231	1431
C84	1.3635	2818	250	2568	1.1695	2417	232	2185



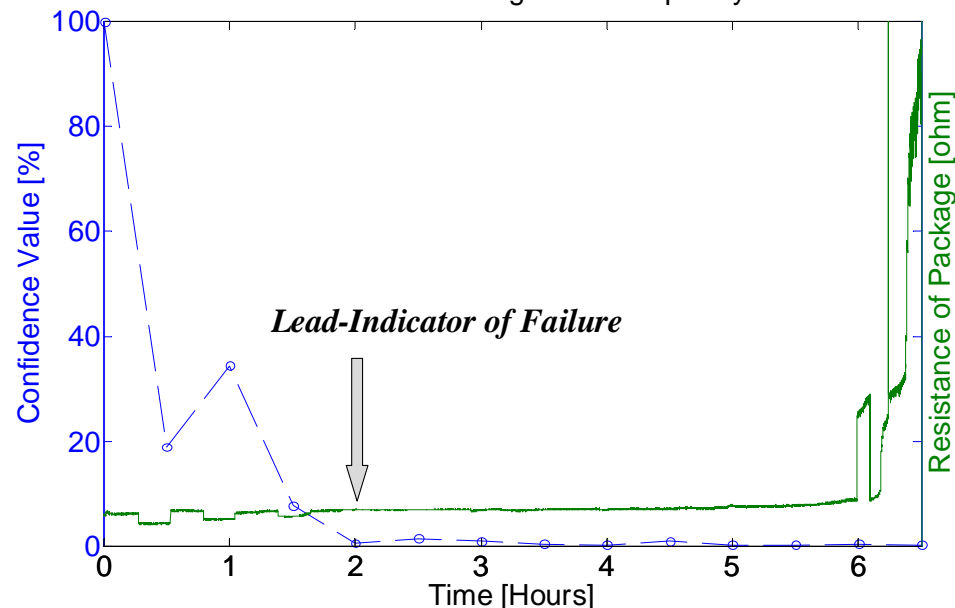
Resistance Spectroscopy Damage Pre-cursors

- Phase Shift vs Time

Electrical Continuity and Measured Phase Angle of Package During Vibration Test



PCB011 Vibration Test-Pkg:U1 at Frequency:127kHz





Summary and Conclusions

Developed leading indicators of failure for shock, vibration, isothermal and cyclic thermo-mechanical loads.

Developed a methodology has been presented to calculate the prior damage in electronics subjected to cyclic and isothermal thermo-mechanical loads.

The correlations indicate that the leading indicators based PHM technique can be used to interrogate the system state and thus estimate the Residual-Life of a component

The presented approach of computing residual life can be implemented prior to appearance of any macro-indicators of damage like crack